LUNAR ORBITER: TRACKING DATA INDICATES INTERESTING GRAVITATIONAL FIELD PROPERTIES

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ABSTRACT

After only a few days in lunar orbit, the first U. S. satellite of the moon has already produced data which has provided new information about the lunar gravitational field. It appears that the spacecraft will not impact on the moon before completion of its photographic mission, but that it will probably do so in about 8 months. Preliminary indications are that the moon has a relatively large pear-shape component, and that its gravitational properties will be of considerable scientific interest.

During the first few days after its injection into lunar orbit, we analyzed the tracking data from Lunar Orbiter I, the first U. S. satellite of the moon. We used a series of sophisticated computer programs especially designed for this task. Our immediate purpose in the analysis was to produce a first estimate of the overall gravitational field of the moon. This estimate was used to predict the variations in the orbit of the spacecraft to enable us to make decisions with respect to control of the mission. A long term objective is to determine the precise properties of the lunar gravitational field. We can achieve this objective only after considerably more data have been accumulated from Lunar Orbiter I and future lunar satellites.

The preliminary results from our analysis of the early data indicate that there is no danger of the spacecraft impacting on the moon before completion of its photographic mission, which involves approximately 8 days for taking photographs and another 3 weeks for reading out the data and transmitting it back to earth. The results further indicate that orbital variations during the photographic period will not significantly degrade the quality of the photographs. In particular, we estimated that the pericenter altitude would decrease by about 8 to 10 km during the first 4 or 5 days of photography and then increase by somewhat less than this amount during the remainder of the 8 days. We considered these results to be sufficiently accurate to permit an orbital transfer maneuver from the initial lunar orbit to a lower final orbit with pericenter altitude very near the optimum value for close-up photography, a maneuver which could not be designed with much degree of confidence prior to this first flight because of the lack of knowledge of the higher order components of the lunar gravitational field.

In our analysis to provide an overall estimate of the lunar gravitational field for mission control, we solved for some 21 coefficients in the expansion of the gravitational potential function in terms of spherical harmonics through degree and order 4 (1). Even though the program is capable of solving for additional coefficients, this number was thought to represent a reasonable sampling of the gravitational components for the intended purpose. A number of the coefficients changed somewhat as the data arc was increased, a situation to be expected due to the short data arc which produced high correlations between the various coefficients. However, short term predictions of orbital variations using complete sets of coefficients gave consistent results. The variety and magnitudes of the coefficients obtained in these early solutions indicate that the gravitational field of the moon has some interesting properties. With one possible exception, we do not consider these early solutions sufficiently precise to allow discussions of particular coefficients in any detail.

The preliminary indications are that the moon has a relatively large coefficient for the third zonal harmonic $(C_{3,0} = -J_{3,0})$, with a value of about 1×10^{-4}. This is the gravitational field component which can be visualized as a very slight tendency toward the shape of a pear superimposed on the essentially spherical figure of the moon, axially symmetric with respect to the polar axis, and with the stem of the pear at the north pole of the moon. As a basis for comparison, the corresponding value for the earth is about 2.5×10^{-6}, or about forty times smaller, with the same sign. Assuming that the density within the moon is uniform and equal to the mean density, we find that the pear shaped component would correspond to a bulge at the lunar north pole of about 0.4 km, a depression at the south pole of the same amount, and an intermediate depression and bulge in the northern and southern hemisphere, respectively, of half this amount. However we do not suggest that this pear shape component constitutes the overall figure of the moon, for all other coefficients also contribute to the figure. These coefficients must be included when they have been determined with some degree of confidence.

The major effect of the third zonal harmonic on satellite motion is that it causes a periodic variation in the eccentricity of the orbit, and consequently a periodic variation in pericenter altitude, with a period equal to that of pericenter revolution. With $C_{3,0} = 1 \times 10^{-4}$, and with the present pericenter altitude of Lunar Orbiter I, it is highly probable that the spacecraft will eventually impact on the surface of the moon. Our preliminary estimate is that impact will occur in about 8 months.

It is of interest to compare our preliminary estimate of the value of $C_{3,0}$ with values discussed by other authors prior to the flight of Lunar Orbiter I. On the basis of an argument pertaining to accommodation of equal stress in the moon and in the earth, Kaula (2) determined a scaling factor to be applied to values of coefficients of the gravitational field of the earth to arrive at estimates of those for the moon. In this manner he estimated $\pm 0.93 \times 10^{-4}$ as an upper value for $C_{3,0}$ for the moon; the magnitude of his coefficient compares favorably with our estimate. C. L. Goudas has made surface harmonic studies, based on several independent sets of coordinates of points on the lunar surface, from which he has derived estimates of $C_{3,0}$. His work and assumptions are conveniently summarized by Kopal (3). From one set of points he determined a value of 0.98×10^{-4} for $C_{3,0}$, but from another set he found about the same magnitude but the opposite sign. We can only say that a value he obtained from one of the sets he investigated compares very favorably with our estimate.

The tracking data used in this analysis was two-way doppler data, providing a measure of the relative velocity between the spacecraft and the stations of the NASA Deep Space Network in Australia, Spain, and California. The main computer program is based on the procedures of differential corrections and weighted least squares, with a twelfth order numerical integration of Cowell type equations of motion. All calculations are performed in double precision.

Tracking data will be obtained from Lunar Orbiter I as long as the spacecraft is in operation. The preferred period for obtaining tracking data for gravitational field determination is after the end of the photographic phase of the mission, at which time spacecraft maneuvers will be curtailed in order to minimize extraneous factors.

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